Renewable and Sustainable Energy Reviews 15 (2011) 3870–3876

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Algae as a sustainable energy source for biofuel production in Iran: A case study

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ARTICLE INFO

Article history:
Received 20 December 2010
Accepted 5 July 2011
Available online 6 August 2011

Keywords:
Algae energy resources
Renewable energies
Biodiesel

ABSTRACT

Algae can be converted directly into energy, such as biodiesel, bioethanol and biomethanol and therefore can be a source of renewable energy. There is a growing interest for biodiesel production from algae because of its higher yield non-edible oil production and its fast growth that does not compete for land with food production. About 50% of algae weight is oil that this lipid oil can be used to make biodiesel. Algae is capable of yielding 30 times more oil per acre than the crops currently used in biodiesel production. Processes for biodiesel production from algae-oil are similar to food and non-food crops derived biodiesel processes. Because of disadvantages of fossil fuels, renewable energy sources are getting importance for sustainable energy development and environmental protection. Among the renewable sources, Iran has high biofuel energy potential. The Iranian government is considerable attention to the utilization of renewable energy, especially biofuels. Iran has enough land in order to algae cultivation that does not compete with food production. A salt lake (Lake Orumieh) in Iran's West Azarbaijan province, Maharlu salt lake in Iran's Fars province, Qom salt lake in Iran's Qom province have given rise to a new species of algae for biofuel. Algae are frequent in the shallow-marine lime stones in Zagros Mountains in north of Fars province. Greenish blooms of algae can be seen in the Persian Gulf and Caspian Sea, south and north of Iran respectively. This study presents a brief introduction to the resource, status and prospect of algae as a sustainable energy source for biodiesel production in Iran. The main advantages of using algae for biodiesel production in Iran are described.

Contents

1. Introduction

Iran and many other countries are seeking new energy sources like biofuels. Developing renewable energy has become an important part of worldwide energy policy to reduce greenhouse gas emissions caused by fossil fuel [1,2]. Today over 80% of the energy comes from petroleum, coal and natural gas. About 98% of carbon emissions result from fossil fuel combustion. Reducing the use of fossil fuels would considerably reduce pollutants; this can be achieved by replacing fossil fuel by renewable fuels. Sustainable renewable energy sources will play an important role in the world's future energy supply [3–6]. Alternative transport fuels such as biofuels are seen as an option to help the transport sector in decreasing its dependency on oil and reducing its environmental impact [7]. Among the existing renewable alternative fuels to fossil fuels, algae have raised great interest [3]. Alga is the most

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1364-0321/$ – see front matter
doi:10.1016/j.rser.2011.07.010

promising non-food source of biofuels that has a rapid reproduction rate and can grow in salt water, harsh conditions, submerged area and sea water. Algae biofuel contains no sulfur, is non-toxic and highly biodegrabable, algae have been of considerable interest in the biofuel production as they can accumulate very high levels of lipid that can be easily transesterified to biodiesel, oil content in microalgae can exceed 80% by weight of dry biomass [8–11]. Biodiesel produced from microalgae is not resource limited and has the potential for yields 50–100 times greater than biodiesel from crops. This high production level can be achieved sustainability with high-energy return on investment and with little impact on food production and prices [12]. Feedstocks such as rapeseed, soybeans, palm oil and sunflower are considered to be first generation biodiesel feedstocks because they were the first crops to be used to produce biodiesel. To reduce the dependency on edible oil, alternative biofuel sources such as non-food feedstocks, have been developed to produce biodiesel. Crops such as jatropha, mahua, jojoba oil, tobacco seed, salmon oil, see mango, waste cooking oils and animal fats are also considered as 2nd generation feedstocks. The cost of biodiesel production, inefficiency and un-sustainability of these 1st and 2nd generation biodiesel feedstocks caused scientists concentrate on 3rd generation biodiesel feedstocks which are derived from microalgae [13,14]. In the recent years much thrust has been put on to examine the possibilities of using algae as a source of bio-oil and biogas for energy applications. The commercial viability of algae-based biofuels production shall eventually depend on economics of the technology. 1 kg of dry algae biomass utilizes about 1.83 kg of CO_2, thus the microalgae biomass production can help in bio-fixation of waste CO_2 with respect to air quality maintenance and improvement [15,16]. The main obstacle for the commercialization of algae-based biodiesel is its high production cost from requiring high-oil-yielding algae strains and effective large-scale bioreactors [17,18]. Many publications describing research on microalgae have been published and several researchers focused on the production of biodiesel from algae oil, which appears to be a good option for biodiesel production, because they are readily available and easily cultured in the laboratory [19–26]. Importance of algae oil as a source of biodiesel has been studied by Demirbas. Based on the results of their study it was proved that producing biodiesel from algae has been touted as the most efficient way to make biodiesel fuel and algae-oil processes into biodiesel as easily as oil derived from land-based crops [3]. Mechanism and challenges in commercialisation of algal biofuels were studied by Singh and his colleagues [9]. The economics of producing biodiesel from algae was studied by Galagher [12]. He concluded that an economically viable algae-to-biodiesel will initially depend on government subsidies and the future price of oil, in addition to optimized biomass yields [12]. A rigorous chemical engineering mass balance/unit operations approach was applied to biodiesel from algae mass culture [27]. Methyl algaeate and ethyl algaeate diesel can be produced largely in a technologically sustainable way albeit at a lower available diesel yield. About 11 square miles of algae ponds would be needed with optimistic assumptions of 50 g biomass yield per day and m^2 pond area. CO_2 to foster algae growth should be supplied from a sustainable source such as a biomass based ethanol production [27]. Kovacevic and Wesseler were studied on cost-effectiveness analysis of algae energy production in the EU. They discussed that biotechnology development, high crude oil prices and high carbon value are the key features of the scenario where algal biodiesel outcompetes all other fuels and a substantial investment into the biotechnology sector and comprehensive environmental research and policy are required to make that scenario a reality [28]. Exergetic efficiency of the environment friendly algal biodiesel production process and renewability of the algal–biodiesel–carbon dioxide cycle were assessed by Sorguven and Ozilgen. The renewability indicator was found to be positive, showing that the algal–biodiesel–carbon dioxide cycle is indeed renewable and any increase in the lipid content of the algae will improve the efficiency of the process [29]. This paper aims to demonstrate an overview of the potential of biodiesel production from algae oil in Iran.

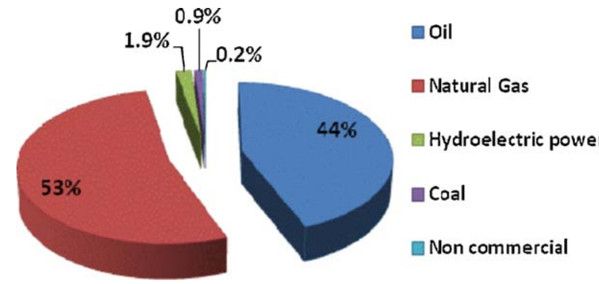

Fig. 1. Total energy consumption in Iran by type (2008) [30–33].

2. Iran's energy status

Iran is a member of the Organization of the Petroleum Exporting Countries (OPEC), ranks among the world's top three holders of both proven and natural gas reserves. Iran is OPEC's 2nd largest producer and exporter after Suadi Arabia. Natural gas accounts for half of Iran's total domestic energy consumption, while the remaining half is predominately oil consumption. The continued exploration and production of the offshore South Pars natural gas field in the Persian Gulf is a key part of Iran's energy sector development plan [30]. Iran has estimated 137.6 billion barrels of proven oil reserves or roughly 10% of the world's total reserves [31]. In 2008, Iran produced 4.2 million barrels of oil per day (bbl/d) equal to about 5% of global production, Iran exported near 2.4 million bbl/d of oil to Asia and European countries, making it the 4th largest exporter in the world in 2008. Iran's 2009 crude oil production was 3.9 million bbl/d [31]. Fig. 1 shows total energy consumption by type in 2008. Iran's estimated proven natural gas reserves stand at 1045 trillion cubic feet (Tcf), 2nd only to Russia in 2010. In 2008, Iran produced 4.1 Tcf natural gas and consumed 4.2 Tcf. Natural gas is expected to grow around 7% annually [31].

Iran's population is growing at a fast pace. It has doubled to 70 million people in only 30 years and much electricity is needed for growing population and economy. Due to infrastructure problems, domestic demands and economic need to export oil and natural gas, these energy sources cannot fully meet future Iranian electric needs. Iran has substantial solar, wind, geothermal and biomass resources. An energy efficiency program with using of renewable energy can help cut electric use considerably and can meet all the future electric needs of Iran. Iran can meet its future electric generation goals thru renewable energy and efficiency for only $20 billion. The production of renewable energy and energy efficiency products would create thousands of jobs, help economy, reduces greenhouse gases and save Iranian oil and gas would be available for export. This paper shows that there is considerable potential for the utilization of algae oil for the production of biofuels in Iran. If these materials efficiently utilized there will be no need to import conventional fuel to the country. Producing biofuels from different sources like microalgae can ideally replace with some share of fossil fuels consumption in Iran.

3. Algae as a source of biodiesel in Iran

Iran, like many other countries is working on projects to find new energy from biofuels. Iranian algae biofuel project is being carried out by researchers at Tarbiat Modares University, Tehran and Shiraz University who succeeded in producing green fuel from the

Fig. 2. Maharlu salt lake in Fars province of Iran has given rise algae for biofuel.

Fig. 3. Urmia salt lake in West Azarbaijan province of Iran has given rise to a new species of algae for biofuel.

algae. The microalgae were isolated during a screening program from soil and water samples collected from paddy-fields of Fars province and the Maharlu salt lake, Urmia salt lake in Iran's west Azarbaijan province, Qom lsalt lake in Iran's Qom province, Zagros Mountains in north of Fars province, Persian Gulf and Caspian Sea, south and north of Iran respectively.

3.1. Algae from paddy-fields of Fars province and the Maharlu salt lake

Maharlu lake located 18 km east of Shiraz at Fars province of Iran (Fig. 2), has salt-water from which salt is obtained. Salt is exploited in a factory at its shore to be used in industries as the water is very much salty. The water body is an exclusive home only for the crustacean "Artemia", and the unicellular algae Dunaliella. The lake is exploited as a mine of different chemicals, mainly by Shiraz Petrochemical Company. Shiraz University succeeded in producing green fuel from the algae.

3.2. Algae from Urmia salt lake in Iran's west Azarbaijan province

A salt lake in Iran has given rise to a new species of algae for biofuel. This is the large salt lake "Urmia" (Fig. 3). Urmia lake located at the north west of Iran in West Azarbaijan province and has got an approximate area of 60,000 km. There are slimy grounds created at round the deltas of this permanent lake.

The salt rate of this lake is very high (3/5 of the Dead Sea) and has got 23% minerals. So, no fish or animal could live there. This lake has turned red as the result of an environmental phenomenon known as the "red tide". Soap-like foam substance produced by algae started to redden Urmia from the East Azarbaizan coast and gradually covered the whole lake. The "red tide" is actually the result of an algal bloom, an event in which marine or fresh water algae accumulate rapidly in the water. Some environmentalists say the phenomenon is caused by nutrient loading from human activities or industrial and city wastewater which include nitrates and phosphates.

Scientists in Iran especially in Tarbiat Modares University and Tehran University are trying to convert these algae to biofuels.

3.3. Algae from Zagros Mountains

Algae are frequent in the shallow-marine in Zagros Mountains outcropping in north of Shiraz (Shiraz is centre of Fars

Fig. 4. Zagros Mountains in Iran.

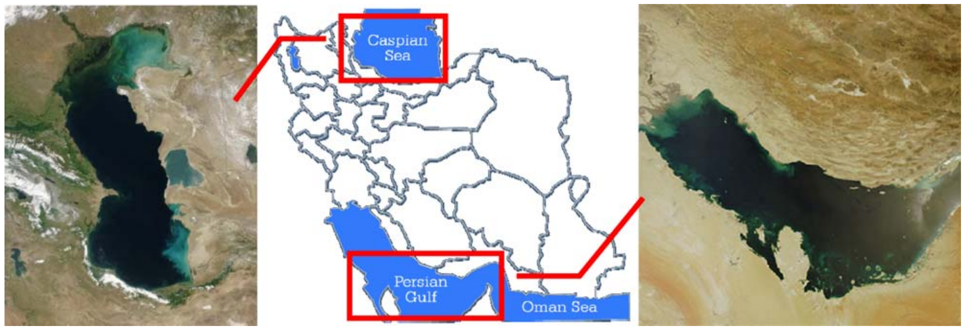

Fig. 5. Algae in the Persian Gulf and Caspian Sea.

Fig. 6. Algae from Qom Lake.

Province) (Fig. 4). Eight of green algae (among 7 dascycladaceans, 1 Udoteaceans) and one red algae are determined [34].

3.4. Algae from Persian Gulf and Caspian Sea

The Tigris and Euphrates Rivers (off shores of Iraq) carry great quantities of silt into the Persian Gulf. The entire area near the river mouths is a river delta interlaced by the channels of the two rivers and by irrigation canals. In the close-up, agricultural areas are visible towards the upper left border, while marshlands and channels can be observed near the rivermouths. Upon opening the full version of the main image, greenish blooms of algae can be seen in the Persian Gulf as well. Two red algae, *Gracilaria salicornia* and *Hypnea flagelliformis*, has been collected from Persian Gulf for producing of biodiesel by Iranian scientists. Blue-green algae (cyanobacteria) and diatoms constitute the greatest biomass concentration, and there are several species of red and brown algae in Caspian Sea. The Caspian Sea is home to 87 species of microphytes and many species of green algae (Fig. 5).

3.5. Algae from Qom Lake

Qom Lake, occupying an approximate area of 2400 km. Qom Lake is a seasonal lake located at the south of Tehran, in Qom province. The area and shape of the lake are varied due to the water running into it from salty rivers and rainfall. Qom Lake is salty lake and algae can be cultivated in this area (Fig. 6).

4. Biodiesel from algae oil

There is a growing interest in algae-based biodiesel for its higher yield non-edible oil production, and does not compete for land with food production. Algae-based biodiesel has a superior yield per hectare over conventional oil crops because algae can be grown in farm or bioreactor [17,35–37]. The comparison of the biodiesel production from algae and oil plants has been described in Table 1.

The typical oil yields from various sources have been listed in Table 2. The rapid growth potential and numerous species of microalgae with oil content in the range of 20–50% dry weight of biomass is the another advantage for its choice as a potential biomass [15,38].

The main components of typical algae are proteins, carbohydrates, lipids and other valuable components, e.g. pigment, anti-oxidants, fatty acids, vitamins, etc. [13,39]. Fig. 7 shows a schematic of the production of biodiesel from microalgae. The first step is the selection of an appropriate species with the relevant properties for the specific culture conditions and products [13,40]. For algae cultivation, most companies pursuing algae as a source of biofuels are pumping nutrient-laden water through plastic tubes that are exposed to sunlight called as photobioreactors or PBR. In PBR system, algae are cultivated in suspension, but the system is

Table 1
Comparison of biodiesel production from algae and oil plants [17,36].

	Biodiesel from algae	Biodiesel from plants
Technology	Cell bioengineering, automatically produced in pilot plants	Agriculture in farm
Production period	5–7 days for a batch cultivation	Several months or years
Oil content	More than 50% in whole cells	Less than 20% in seeds or fruits
Land occupied	0.01–0.013 ha for producing 103 L oil	2.24 ha for producing 103 L oil
Cost performance	$2.4 per liter microalgae oil	$0.6–0.8 per liter plant oil
Development potential	Unlimited (work just beginning)	Limited (works have been done)

Table 2
Typical oil yields from the various biomasses [3,13,15,17,16,42,43].

S.N.	Crop	Oil yield (lit/ha)
1	Rubber seed	80–120
2	Corn	172
3	Soybean	446
4	Safflower	779
5	Chinese tallow	907
6	Camelina	915
7	Sunflower	952
8	Peanut	1059
9	Canola	1190
10	Rapeseed	1190
11	Castor	1413
12	Jatropha	1892
13	Karanj	2590
14	Coconut	2689
15	Oil palm	5950
16	Microalgae (30% oil by wt.)	58,700
17	Microalgae (70% oil by wt.)	136,900

closed and water is circulated by pumps. Artificial light and heat are used. In a closed system (not exposed to open air) there is not the problem of contamination by other organism blown by the air, the problem for a closed system is finding a cheap source of sterile CO_2. Another main cultivation system is open pond that refers to a simple open tank or natural ponds. Algae are grown in suspension with additional fertilizers. Gas exchange is via natural contact with the surrounding atmosphere and solar light [9]. Microalgae can be harvested using microscreens, sedimentation, centrifugation, flocculation or membrane filtration. The harvested biomass is then dried and oil is extracted. Various methods for the extraction of lipids from microalgae have been reported in literature, methods are expeller/oil press, liquid–liquid extraction (solvent extraction), supercritical fluid extraction and ultrasound technique [15]. The most popular extraction method is Soxhlet extraction using hexane as a solvent and an extraction time of 4 h, oil will be separated from the solvent extract by distillation process, then oils are converted to biodiesel using transestrification method [40,41]. Biodiesel is typically produced through the reaction of algal oil with methanol in the presence of catalyst to yield glycerine and methyl esters, this process for making biodiesel is relatively simple and can be low extremely low-technology, the process is known as transestrification (Fig. 8). Actually biolipid algal oil consists of hydrocarbon compound that are not suitable for diesel engines, so it can be modified for use in engine using transestrification. Biodiesel include no sulfur or particular matter that contribute to air pollution. Sulfur and PM have been responsible for black smoke and sour odor problems commonly attributed to dirty diesel fuel. Biodiesel has greater lubricity than petroleum diesel, in addition algal biodiesel is a carbon-natural fuel, which means it assimilates about as much CO_2 during algal growth as it release upon fuel combustion [12].

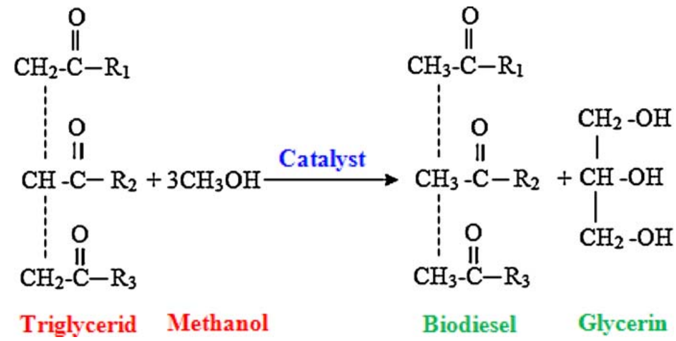

Fig. 8. The transestrification process [8,44].

Biodiesel produced from microalgae has been found to have properties, such as density, viscosity, flash point, etc. [25]. Most of these parameters comply with the limits established by the American Society for Testing and Materials (ASTM) for biodiesel quality [10-Ahmad]. Algal biodiesel has also been found to meet the International Biodiesel Standard for Vehicles (EN14214). A comparison of typical properties of fossil oil and bio-oil obtained from microalgae indicated that bio-oil from microalgae has a lower heating value, lower viscosity and higher density compared to fossil oil (Table 3).

5. Future prospects

Algae have great potential as a sustainable source for the production of biodiesel. Research for the production of biofuels from microalgae is in the beginning stages and there is a substantial need for more research to study other economic issue related to biofuels. Geographically, Iran has Caspian Sea in the north and Persian Gulf in the south that has natural advantages for algae culture. Iran has different salt lake that helps scientists advance algae-based biofuel technology. Authors of this paper recommend to government to start to investigate the following chart in order to make industrial sites for biofuels, specially, Urmia, Qom and Shiraz, with their close to the lakes, have the potential to be algal fuel in Middle East (Fig. 9).

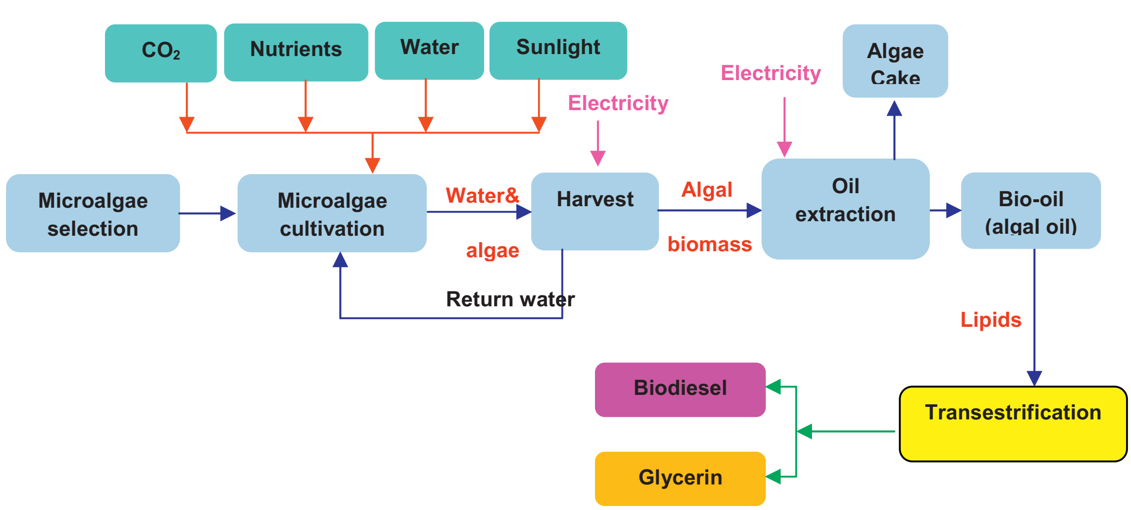

Fig. 7. Production of biodiesel from microalgae.

Table 3
Comparison of typical properties of fossil oil and bio-oil from microalgae [13].

Properties	Unit	Standard	Bio-oil from microalgae	Fossil oil
Density	kg/l	ASTM D-6751	1.16	0.75–1
Viscosity	Pa s	ASTM D-445	0.1@40 °C	2–1000
Heating value	MJ kg^{-1}	ASTM D-6751	29	42
Stability	–	ASTM D-6751	Not as stable as fossil fuels	–

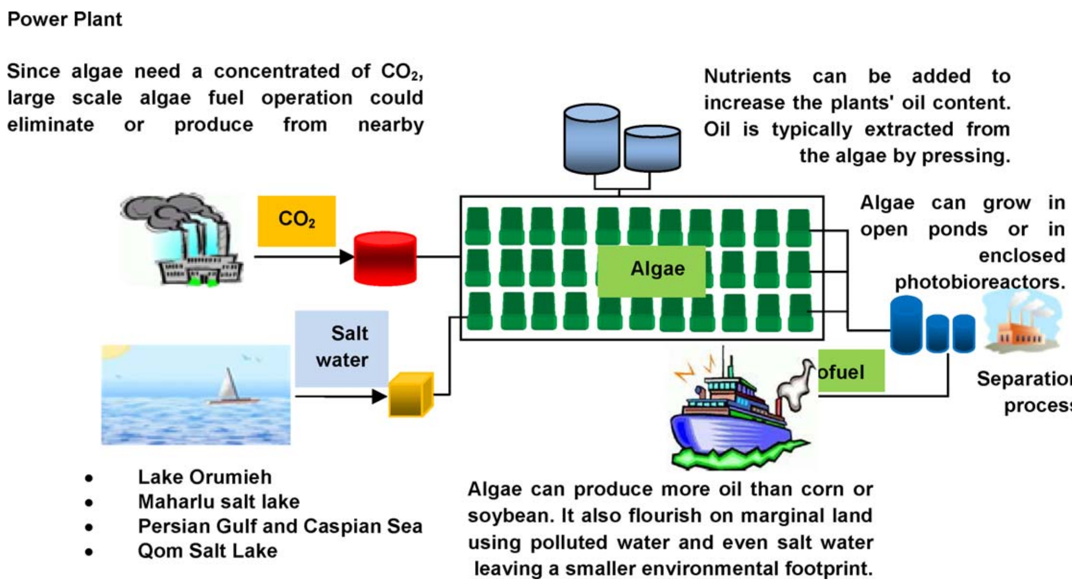

Fig. 9. Recommended process for the production of biodiesel from microalgae.

This paper showed that there is a considerable potential for the utilization of algae for the production of biodiesel in Iran. Producing biodiesel from the microalgae can ideally replace 5% of total diesel fuel consumption in the first step. By managing this biofuels, an AB5 (5% Algal Biodiesel and 95% diesel fuel) can be an optimum fuel for compressed ignition (CI) engine since there is no major engine modification required to use biodiesel. The authors are strongly recommended these techniques so Iran can reduce import og diesel fuel. Sure, there is a substantial need for more research to study other economic issue related to biodiesel.

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